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TECHNIQUES OF SPACE PHOTOGRAPHY

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by Robert L. Summers
Lewis Research Center
Cleveland, Ohio

TECHNICAL PAPER proposed for presentation at National Electronics Conference, 1967 Student Program, Chicago, Illinois, October 24, 1967

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D.C. • 1967

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TECHNIQUES OF SPACE PHOTOGRAPHY

by Robert L. Summers

The rocket engine has given man the capability to leave the Earth and reach out into space--to the Moon, the planets and soon beyond. While the capability is due to the rocket engine, the ability to utilize such a capability rests on instrumentation. My topic today is a discussion of the role of one type of instrumentation, the camera, in the exploration of space.

The program of space exploration of this nation is being conducted by the National Aeronautics and Space Administration. NASA, as you know, is an agency of the United States government, created by act of Congress, and charged with the conduct of this nation's space program. NASA is especially charged to conduct a program of peaceful exploration and exploitation of space for the benefit of all mankind.

My role today is not as apologist for the space program. The reasons for such a program are many and varied. It is sufficient to say that if there is a goal, it is the nature of man to try until he succeeds to that goal. Space flight has been the dream of man since he first looked to the heavens. And, we are now standing at the end of the first decade of this dream that we call the space age.

From the first decade of this man's greatest adventure, I have selected four missions which I will discuss. The four missions chosen are photographic, or include photographic subsystems. By limiting the number to four we may look at each in detail, and still compare and contrast a group of similar missions.

When we consider the camera as an instrument or instrument system, we must remember that man has an innate set of sensors which enable him to sense his environment. In addition, he has evolved a complex set of aids which extends the range of his senses. With these aids--we call them instruments--we are able to see that which is too small, to hear that which is too quiet. Through transducers, we sense parameters of our environment that were previously unattainable. Through telemetry, our senses are extended to that which is unreachable or intolerable. Photographs are an extension of man's most sensitive sense, the eye. And, since we cannot travel to see the other planets, we utilize photography. We cannot practically return photographs from other planets, so we utilize the techniques of television.

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Three of the four missions to be discussed (fig. 1) are lunar probes. The first of these was Ranger, now terminated, in which a probe was launched to impact on the Moon. Prior to impact, camera systems were to telemeter photos back to Earth. The second mission, Surveyor, is designed to soft-land various instruments, including cameras on the Moon and then telemeter data to Earth-bound investigators. The Lunar Orbiter is the third lunar mission. Its goal is a low lunar orbit from which photos and measurements may be made. The immediate goal of these probes is the preparation for the first manned lunar missions--Apollo.

The fourth mission (fig. 2) is Mariner IV whose mission was to fly-by Mars and provide data on Mars, and the near Mars space. One phase of Mariner was a series of Martian surface photos. Each of these missions has a similar objective--to provide photographic information of surface topography of the Moon or Mars. Differences in the mode of conducting each of the missions results in four very different camera systems.

The necessity of using probes in trying to expand our knowledge of our neighbors in space becomes evident when we realize just how restricted our Earth-bound observations are due to the nature of the atmosphere, (fig. 3). The very properties of the atmosphere which nurture and protect life also inhibit our view of the universe. Only a very narrow band of the electro-magnetic spectrum can penetrate the gaseous blanket surrounding the Earth. Even in this narrow range of frequencies, centered around the visible, radio and infra-red, severe distortion of incoming information occurs. Air motion causes the apparent twinkling of the stars. The same mechanism limits Earth-bound lunar photos to a resolution of about $\frac{1}{2}$ mile. The TV camera systems carried by these missions overcame two immediate problems, that is, distance and the semi-opaque atmosphere.

The launch and flight profiles of the four missions are very similar, so that only one need be described. The Ranger launch will be recounted as typical. All four missions (fig. 4) used a common launch vehicle, the Atlas-D. This is the same as was used in the manned Mercury flights. In Gemini, Atlas was also used to launch the Agena target vehicle; Agena in modified form was also used as a second stage in the Ranger launch. Atlas alone can place about 1800 lbs. into a 300 mile orbit; the Atlas-Agena can put nearly 6000 lbs. into the same orbit, or send 950 lbs. to the Moon. In all the missions to be described, the Lewis Research Center had the responsibility for the launch vehicle.

The Ranger spacecraft (fig. 5) was designed by the Jet Propulsion Laboratory of the California Institute of Technology. The craft consists of an open hexagonal truncated cone as the main structure with the solar panels and the parabolic dish antenna hinged to the structure. Not visible, on the underside of the structure is the rocket used for course corrections. The TV system is contained in the cylinder atop the main structure. The cameras look out through the side, inclined at an angle of about 37 degrees. The top-hat structure above the camera system is an omni antenna to receive commands from Earth, and transmit to Earth if the parabolic antenna is not usable. Six compartments about the base of the structure contain various electronics systems and batteries. Ranger is a second generation spacecraft, in that the craft is stabilized in flight by gas jets which maintain some preferred orientation.

At launch (fig. 6) the dish antenna is folded under the craft and the solar panels are folded up. The Ranger is mounted on the Atlas-Agena and covered by a protective shroud for the launch through the atmosphere. The window through which the camera see the lunar surface is also visible in this view.

If we think (fig. 7) of the allowable launch corridor to the Moon as a tunnel, it's mouth--the launch window--would be 10 miles in diameter approximately 115 miles above the Earth. The Earth-Moon distance is about $\frac{1}{4}$ million miles, however, the Ranger will travel an additional 90000 miles along the curved trajectory. The launch sequence consists of the Atlas lifting the Ranger-Agena combination to about 90 miles where the Atlas and the spacecraft shroud are jettisoned. The Agena then fires and injects itself and Ranger into a 115 mile parking orbit. The Agena shuts down; the orbital velocity is about 5 miles per second. After a period of coast, dependent upon the launch profile, the Agena fires again and injects the Ranger through the launch window. The escape velocity is about 7 miles per second, and must be accurate to 1 part in 1500 for mission success. If the Ranger enters the launch window within the specified limits, enough propulsive power is available in the Ranger rocket engine to make midcourse corrections. After injection, Agena separates, fires retro-rockets to slow itself, and falls away. The launch variables are the launch azimuth and the length of coast in the parking orbit; the constraints on the launch, imposed by nature and man, are:

(1) The launch site is moving, due to the earth's rotation, at a speed of nearly 1000 mph.

(2) The Moon in its orbit is moving with a speed of about 2000 mph.

(3) The required escape velocity can only be attained outside the Earth's atmosphere.

(4) Launch azimuth is restricted to the range of 90 to 114° so that re-entering portions of the vehicle will not endanger populated areas.

(5) To receive the Ranger picture transmissions, the main tracking antenna at Goldstone, California must have the impact point on the Moon in sight during the final portion of the flight.

The ideal approach (fig. 8) to the Moon for the Ranger mission is a near vertical approach with low angle lighting to enhance surface shadowing; further, the Ranger must have its dish antenna pointing toward Earth. The only time the Ranger could fulfill this flight profile was in the third quarter of the lunar month. Considering all restrictions and restraints, the Ranger could be launched only during a 1 to 4 hour period on six consecutive days in the third quarter of the lunar month.

After launch (fig. 5) Ranger has sufficient battery power for only about 20 hours of operation and must for most of the mission rely upon solar power. Squibs (explosive pin-pullers) unlatch the solar panels and loading springs cause the panels to deploy and lock into position. Small cold jets cause a controlled tumble until photocells, which sense the sun direction and control the gas jets, cause the craft to stabilize with the panels locked on the sun. The craft continues to roll as the dish antenna is unlatched. Photosensors on the antenna sense the Earth and stop the roll leaving the Ranger stabilized in what is termed the cruise mode. Antenna angle is also controlled to maintain an "Earth lock".

Earth transmission to the craft was at 890 mc., with command data in digital form. Ranger receives the commands, compares them to a list of allowable commands and retransmits the command back to Earth as a check. Ranger also multiplies the received carrier frequency from Earth by a fixed number and uses this new frequency as the carrier for retransmission back to Earth. These frequencies (890 mc. from Earth and about 960 mc. back to Earth) are modified by Doppler effects and allow velocity determinations along the line of transmission to an accuracy of about $\frac{1}{2}$ inch per second.

The total flight time (fig. 9) to the Moon is some 68 hours, most of it spent in cruise mode. Enough tracking data is received in the first 16 hours to calculate the midcourse correction. Ranger receives the commands from Earth, leaves cruise mode, points itself in the proper direction and fires its' engine for the proper length of time. Ranger then repeats its' tumbling act to return to cruise mode; in the last three Ranger missions, the midcourse correction allowed impacts on the Moon within 10 to 20 miles of the desired point. For the next 50 hours, Ranger continues to the Moon, transmitting engineering measurements on about 110 onboard parameters. For the first 50 hours of the flight, the Earth's gravity is slowing the Ranger; then the Moon's attraction takes over and Ranger begins to accelerate toward the impact point.

About 1 hour before impact (fig. 10) Ranger orients itself so that the cameras look down the trajectory; the panels no longer point at the sun so that power is derived from batteries. The Earth lock is maintained for the dish antenna since this is the link over which the Ranger photos will be transmitted. To this point, communications to Earth has been maintained by a 3 watt transmitter. For the critical part of the mission, twin 60 watt transmitters in the camera system are turned on for the actual picture transmissions. Fifteen minutes before impact the picture taking sequence begins. Although the other missions to be discussed differ in detail, a very similar sequence of events occurs in carrying out the missions.

The ranger camera system (fig. 11) consisted of six vidicon cameras. The lower three were 76 mm., f/2.0, while the upper were 25 mm., f/0.95. All six cameras use the same mode of operation, shuttered images and a slow scan. On the center two cameras, the vidicon scan area was a square 0.44 inch on a side, exposure time was 1/200 second. A 800 line scan of the frame required 2.56 seconds, about the same length of time was required to erase and prepare the vidicon for the next photo. The outer four cameras used a smaller scan area, 0.11 x 0.11 inches, a 200 line scan and an exposure of 1/500 seconds. The smaller scan area allowed faster operation of these cameras; 0.2 second was required for picture read-out, with 0.8 second between exposures.

The center cameras--denoted F_a and F_b for 'full frame'--alternated picture transmission over one of the 60 watt transmitters. The F cameras transmitted at 959.52 mc. along with 15 points of camera system engineering data. The outer P cameras--for partial scan--alternated over the second transmitter at 960.58 mc. with 90 points of data to identify the photos of both channels. The 3 watt transmitter continued to transmit until impact.

The telemetered data from Ranger (fig. 12) was received on antennas at tracking stations scattered about the globe. These 80 to 90 foot-diameter parabolic antennas receive the routine tracking and engineering data and then forward it to the JPL team by conventional ground communications methods. However, the photos are considered too valuable to be entrusted to these ground links; the picture information is contained in a 200 kc. band-width and could be badly distorted. The Goldstone station in California is the only tracking site which has all the required equipment to reconstruct the photographs, this is the reason that Goldstone must have the impact site in view at the time of impact.

Picture transmission begins (fig. 13) when the resolution is about the same as from Earth. The grid lines are imposed in the camera itself. Light levels on the Moon were poorly defined before the Ranger VII mission, so that the RCA design engineers chose camera settings to cover a range of 2500 to 30 foot-lamberts--equivalent to high noon and dusk on Earth--with usable photos from one or more of the cameras. The contrast in this frame is poor; for later missions Ranger VII provided the lighting data which yielded improved contrast.

A new concept of the Moon began to appear as the three Ranger missions provided coverage of limited surface areas with resolution 1000 times better than was previously available. Smooth rolling slopes replace the previously imagined craggy peaks, (fig. 14). This photo of the crater Alphonsus shows the adjacent Mare--notice the difference in small crater density, which infers a difference in age. The rills seem to indicate the possibility of surface activity--some investigators after viewing these photos began to talk of activity on the Moon akin to volcanic activity of the Earth. Each of the Ranger missions transmitted over 4000 photos of the Moon to Earth. Then as the P camera system of Ranger IX transmitted a portion of its' final frame, (fig. 15) the JPL team turned its' attention to the next lunar probe, Surveyor.

In Surveyor (fig. 16) the camera system is conventional by Earth standards. The complexity of Surveyor enters because it must land its' camera, along with other instruments on the Moon with minimum shock. Two omni antennas and a planar antenna communicate with Earth. Once on the Moon, the solar panel and planar antenna are locked on the sun and Earth, respectively. The various electronics of the Surveyor system are contained in the thermal compartments for protection against the extremes of lunar temperature. The temperature on the Moon varies from 250° above zero at noon, through zero within an hour of sunset, to 260° below zero in the lunar night. The Surveyor system includes several cameras as well as other experiments, such as a surface sampler which digs into the Moon and samples the lunar surface.

Two radar systems control the Surveyor approach to the Moon. The first initiates the approach procedure; the second measures the approach parameters and controls the vernier rocket engines. A time-lag of over two seconds in communications to and from Earth requires a self-contained approach control system.

Surveyor differs from Ranger in its flight mode in that the Surveyor senses the sun and the star Canopus to control its orientation; this gives a more accurate control of the cruise mode than the simple 'Earth lock' of Ranger. Canopus is the second brightest star in the sky, and is located near the South pole; the sun-Canopus combination is used as a reference in the majority of space probes for stabilizing the craft orientation. One further difference in the Surveyor launch and flight is of interest. The other three missions of interest tonight used the Atlas-Agena; the soft-landing of the Surveyor requires a large amount of rocket power to slow its' descent. This in turn required a launch vehicle capable of sending about 1 ton of spacecraft to the Moon.

The booster for this mission is the Atlas-Centaur (fig. 17) combination; Centaur uses liquid oxygen and hydrogen as propellants and can send 2300 lbs. to the Moon. Centaur, and Atlas also, uses a 'balloon structure'; structural strength is derived from internal pressurization. The Centaur skin is 0.014-inch thick and is the main structural member. Fiber-glass panels cover the Centaur to inhibit boil-off of the cryogenic fuel; these panels are jettisoned once outside the atmosphere.

At launch (fig. 18) Surveyor weighs about 2200 lbs.; about 60 percent of this weight is in the main retro-motor. This engine provides the majority of the thrust for slowing the approach; minor thrust corrections are made, through radar control, by three small vernier engines. These vernier engines also provide the thrust for the midcourse maneuver.

This illustration also provides a good view of the landing strut, shock adsorber and aluminum honey-comb landing pad. The structure is highly polished to reflect heat; the paint patterns for passive thermal control give the gas storage bottles a beach-ball appearance. The top of the instrument thermal package is mirrored to reflect heat.

The terminal descent of Surveyor begins about 30 minutes before touchdown when Surveyor aligns its main retro with the flight vector. At retro burnout, the empty casing is jettisoned; the engine has reduced the approach to 240 mph from the 6100 mph before firing. The vernier rockets, answering the commands of the approach radar, control the last 5 miles of the flight; the vernier engines shut down at about 13 feet above the surface having decreased the velocity to $3\text{-}\frac{1}{2}$ mph. Surveyor falls the final distance and touches the Moon at a velocity of 10 mph. Only 620 lbs. of the Surveyor's launch weight remains; in the Moon's reduced gravity, the Surveyor only weighs about 90 lbs.

At touchdown, the mast holding the planar antenna and the solar panel is in a retracted position and will require battery power to deploy. This power is derived from onboard batteries since the solar panel is not positioned to receive energy from the sun. As protection against failure of the mast assembly, Surveyor has the ability to transmit photographs over the omni antenna system. This is done before raising the mast so that if the batteries are depleted in trying to deploy, some data might be salvaged.

Having survived the landing, Surveyor must still survive the extremes of lunar environment. The electronics are protected from the frigid cold of lunar night by 75 sheets of aluminized mylar and electrical heaters. To prevent overheating, mechanical thermal switches open and close thermal paths to radiators. During operation, the system internal heat presents as severe a heat load as the sun's radiation.

The single operating camera of Surveyor I was mounted at about eye level; its optics and vidicon characteristic gave it about the same resolving power and light sensitivity as the human eye, (fig. 19). The camera is mounted vertically and sees the lunar surface through a mirror;

azimuth and elevation control allows the camera to see all of the lunar surface, except that which is blocked by the Surveyor structure. A filter wheel allows pictures to be taken through five different filters: clear, polarized, blue, green, or orange. A lens control system allows adjustment of focal length, focus and iris; two choices are given for the shutter, an exposure of 150 ms. or manual control.

About 14 pictures were transmitted (fig. 20) in a 200 line scan mode before raising the antenna and solar panel. After the deployment, the scan rate was 600 lines (fig. 21) with a noticeable improvement in quality. The object in view in many of the initial photos is the foot of the Surveyor. Instruments mounted on the struts measured the impact of the Surveyor on the moon; from the impression made by the foot, estimates of the bearing strength of the Moon's surface were made.

A color disk was also provided to correct the color content of the pictures taken through the colored filters. The received images were reconstructed on Earth to provide true color photos of the lunar surface. Except for the Surveyor, the color content of the lunar surface is nil. The Moon appears only as a scale of greys.

A new technique (fig. 22) was applied to the Surveyor pictures to enhance their quality. Computers were used to analyze the signals and photographs to remove noise, distortion and improve contrast. The technique is quite powerful, being able to correct for motion, focus and, to a degree, for grain size. In these photos objects near the spacecraft about 1/50 of an inch across are resolved; this is about 1000 times better than Ranger and betters Earth resolution by a factor of 10^6.

From the photographs such as this, and knowledge of the landing parameters, the bearing strength of the Moon's surface is estimated to be about 5 psi--about the same as wet sand. Before Surveyor, it had not been proven that this landing method, the same as is to be used in Apollo, was feasible. It was feared that the lunar surface would not properly reflect the radar beam used to control approach due to a thick dust layer. Some said that any craft landing would be swallowed by this dust blanket.

With the team at JPL still busy with Surveyor, if we turn to Boeing we find a similar team busy with Lunar Orbiter, (fig. 23). Orbiter has the same essential features as the other missions--solar panels, directional and omni antennas, a propulsion system, and attitude control. But, its photographic mission of orbital survey yields an interesting and unusual photographic system.

The Orbiter is launched (fig. 24) by the Atlas-Agena toward the Moon; its goal is a lunar orbit, with 128 mile perilone and 1150 mile apolune. From this initial orbit, the Orbiter's engine fires to lower the perilune to about 28 miles; the Orbiter's photographs will be taken from this altitude.

Before launch, a series of survey sites near the lunar equator are chosen for Orbiter to photograph. The path of Orbiter is such as to pass over the equator near to the terminator. As the Moon rotates, the various sites pass under Orbiter with low angle lighting to give good relief shadows. The sites chosen are the possible landing sites for the manned lunar missions of Project Apollo.

The camera system (fig. 25) of Orbiter is contained in an egg shaped pressure shell. Two cameras--a 24-inch focal length, high resolution and a 3-inch focal length, medium resolution--view the Moon through a quartz window, and is protected in turn by a thermal door which opens for each photographic pass. Orbiter also provides additional data about the near lunar space through micrometeoroid and radiation detectors; from tracking the Orbiter, the Moon's gravity can be studied and minor variations charted.

In the Orbiter's photographic subsystem (fig. 26) roll film is exposed, developed, stored, and later the images are scanned and transmitted to Earth. The primary divisions of the system are the cameras, the processing, and the readout phases. The 24-inch lens is a f/5.6 structure with focal plane shutter; the 3-inch lens is also f/5.6 with between the lens shutter. Both cameras have ground controlled shutter speeds of 10, 20 and 40 ms. Both cameras operate simultaneously and expose different areas of the film. The exposed film then consists of alternating exposures from the two cameras. The film used is slow--its exposure index is 1.6. High speed film is very sensitive to radiation fogging; also, the high definition film, such as was used, has fine grain size, which implies in turn, a slow film. A two hundred foot roll of 70 mm film was used; this allowed a total of 195 dual exposures. One edge of the film was preexposed before launch with resolving power charts and densitometric grey scales as a method of calibrating the readout, transmission and receiving systems.

The development processor is based on the Kodak 'Bimat' process. A web containing a single solution developer-fixer is pressed against the exposed film. The developed and fixed negative is dried and passed through the looper and readout to the film takeup. The flow of film through the processor cannot stop, or sticking of the film to the web occurs. Since the film exposure rate is not constant, loopers capable of storing 20 frames act as buffers between the different phases of the system. The readout system requires an average of 40 minutes to read each pair of images so that only spot readout is made during the photo taking portion of the mission. After all the film is exposed and developed, the developer web is cut; the film begins to rewind as readout proceeds. Photo readout is in the reverse sequence and proceeds from the last photo to the first.

Since Orbiter is about 28 miles above the surface of the Moon and traveling at 4500 mph, some blurring of the image is possible. A sensor in Orbiter scans the lunar surface through the 24 inch camera and by comparing the light on sequential scans determines the image motion. This information is fed to platens holding the film to develop film motion to compensate for the Orbiter's movement.

The readout system (fig. 27) is a flying spot scanner. An electron beam generates a scan line on a phospor coated drum; high beam intensity means heat, so the drum rotates to avoid burning the phospor. The scan line is focused onto, and moved across, the film by the scanner lens; Scan width is 1/10 inch, 17000 lines are required to scan the 70 mm film width. The scan spot diameter is 0.0002 inches; 20 seconds is required to scan one 1/10 inch segment of film. The light passing through the film is focused onto a photosensor and then, through amplifiers and transmitters, is passed to Earth. Each pair of photographs requires 116 of the 1/10 inch segments and requires 40 minutes. The total set of photographs may be readout as many times as decired.

For image reconstruction, (fig. 28) the received signal on Earth is displayed on a kinescope and recorded on 35 mm film; each 1/10 inch scan requires nearly 17 inches of film. The individual strips--116 per pair of photographs--are then assembled into a finished photograph--14 by 55 inches for the pair. This reassembly process gives the finished photos a venetian blind appearance. As the photographs are reassembled, the preexposed data on the film edge allows for corrections in the image as recorded on the 35 mm film.

Since the development process cannot be stopped once started, there is a necessity to take the photos at some minimum rate; if one of the survey sites is not at hand, the photo becomes a snapshot of opportunity. The photographs of Copernicus from Orbiter are interesting (fig. 29) because of the new perspective. On the horizon, the crater of Copernicus--some 30 miles in diameter and 2 miles deep--in the center the keyhole shaped crater Fauth; and in the foreground, the unusual domes first discovered in Orbiter photos. The origin to these domes is postulated as volcanic by some of the experts.

The same area is shown in this photo (fig. 30) taken from Earth through the 120-inch telescope of Lick Observatory. The central crater is Copernicus, some 30 miles south is the crater Fauth. At the time Orbiter took the previous photo, it was south of Copernicus, looking north.

In the high resolution photograph (fig. 31) Copernicus fills the center with Fauth just visible in the foreground. Due to the oblique view, the distance is fore shortened; the distance is 180 miles from the bottom of the photo to the Gay-Lussac Promontory on the horizon. The rounded features and the apparent leveling of the crater floor are evident in this view.

The final mission (fig. 32) to be discussed is the Mariner IV--a Mars fly-by. The photographic system of Mariner was one of eight experiments for the mission; instruments were to monitor the space between Earth and Mars, as well as to study the Martian surface and atmosphere. The Mariner was an eight-sided hat box with the camera protruding through the base; the usual assortment of antennas and solar panels are used. Temperature control of the structure was provided by the venetian blind array of shutters, controlled by bi-metallic elements. Closed, the louvers were highly polished; with increasing temperature, the louvers opened to expose blackened radiating surfaces. Solar sails on the solar panels reacted to solar light pressure and were used to stabilize the Mariner's attitude in space--an analog of the wind-jammers of old.

The Mariner launch differed from the Ranger launch only in details and degree. The Mariner launch could only be carried out for a period of a few hours each day for about two weeks every two years; from launch to encounter, 240 days would elapse. At encounter, the Earth was 1-1/3 million miles away; signals to and from Mariner were 12 minutes in transit. Mariner had traveled 325 million miles in eight months in order to spend about 12 hours near Mars making automated observations.

To perform its mission, Mariner would pass below the planet, hook up behind Mars due to gravitational attraction and be occulted by the planet. The aiming point was an altitude of 5700 miles. At this altitude, usable photographs would be obtained; later, the Mariner radio signals would pass through the Martial atmosphere as the spacecraft flew behind the planet. From signal distortion, it was expected that an estimate of the Martian atmospheric density and extent could be made. The altitude achieved at encounter was 6100 miles--essentially a bull's eye.

The transmitter frequency on Mariner was 2300 mc, crystal controlled from Earth with short term stability of about 1 part per 10^{11}. The occultation caused the transmitted signal to suffer phase, amplitude and frequency distortions. From this data, an estimate of pressure of 5 to 6 mb (4 to 5 mmHg) and an atmospheric temperature of about -100° F was derived.

The picture taking process occurred some 9 hours before closest approach and lasted about 1/2 hour. About 1 hour after closest approach the occultation, lasting about one hour, occurred. Later, as the Mariner cleared the near Mars space, the transmission of the stored photos began.

The camera used in Mariner (fig. 33) was a Cassegrain reflecting telescope-vidicon combination. The optics had a 12-inch focal length and 1-½ inch aperture. The exposure time was 1/5 second with the shutter automatically cycling at 48 second intervals. Red and green filters were placed over the camera alternately.

Due to the distance involved, the transmission of data requires digital techniques at a fairly slow pulse rate; for Mariner, the rate was 8-1/3 bits per second. The scan area of the camera vidicon was 0.22 x 0.22 inches. This area was divided into a 200 x 200 matrix of points to be scanned and digitized. The vidicon responded to a 30 to 1 range of intensities; this range was divided into 64 equal increments by a 6 bit binary scale. Automatic video gain adjustment was used so that at least 15 of the 64 increments were included in each photo. The total picture consisted of 40000 contrast words of 6 bit each--a total of 240000 bits--at 8-1/3 bits per second, transmission of a single photograph required nearly 8 hours. Photos were taken at 48 second intervals so that a method of storing the picture data was necessary. A tape recorder recorded the picture data on 300 feet of 1/4-inch two-track tape; this gave storage for about 22 frames. At the scanning rate of 48 seconds per frame, about 33 frames would be exposed as the camera traversed the face of Mars, therefore, every third frame was rejected by the recorder.

As Mariner approached Mars, the camera searched through a 180° arc until the wide angle sensor saw the planet and locked on, with the camera shutter cycling. As the narrow angle sensor saw the planet's limb, the recorder was given a command to start recording the digitized picture.

As the playback sequence showed later, the first photos (fig. 34) caught the Martial limb; the first three transmissions, extended from the limb almost to the equator. The techniques of enhancement (fig. 35) were also applied to the Mars photos to improve the quality; in addition, the Mariner repeated its playback of picture so that missing data might be reclaimed. The path of the Mariner photos across the Mars surface from limb to terminator (fig. 36) was not too satisfying to buffs of Martial canals; the path covers an area not too rich in these surface features. The photos did yield interesting results; (fig. 37) near the middle of the photo process, the camera angle and lighting gave photos that were hailed as the most significant scientific photos to date. Surface resolution was about 2 miles; analysis showed a crater size-density distribution nearly identical to that of the Moon.

As the camera approached the terminator (fig. 38) near the Martian south pole, the polar 'ice cap' became evident as a thin layer of hoarfrost on the crater rim.

The four missions described are in a sense primitive; they represent an initial survey of our space neighbors by use of the robot eyes of spacecraft. But primitive or not, we have in a few short years advanced our knowledge of the Moon and Mars by an increment as great as, if not greater than, the accumulated knowledge of all the years of man. Man has studied the Moon for eons, measured its motion, probed it with radar, scanned it with spectrographs. But all of this failed to produce the details that the photos of

Ranger, Surveyor and Orbiter gave us. Soon these photos will be filed and forgotten by all but the historian as man takes his first step on the lunar surface.

The Mars photos will stand longer--supplemented by data from forthcoming missions; until man feels ready to commit himself to true interplanetary exploration. Life on Mars has long been a dream of the science-fiction writer; Mariner IV did not disprove the existence of Martian life; (neither did it prove it) this must wait for later more sophisticated missions.

None of these missions--from countdown zero to project finish and success--would have been possible without the science-the art-of instrumentation. Space flight and rocketry are often compared to the early days of the automobile and the airplane; the comparison is often instructive. But, there was and is no seat-of-the-pants flying in space. Instrumentation provides the electro-mechanical jockey that guides the mission.

While most of the concepts of measurement utilized in space instrumentation are not new, a great deal of effort is expended in making a flight instrument package lighter, or more sensitive, and always, more reliable. This in turn gives us an immediate benefit here on Earth in terms of the improvements of our day-to-day measurements.

Through the rocket, man found it possible to enter into the space age; through instruments he has made it a practical reality.

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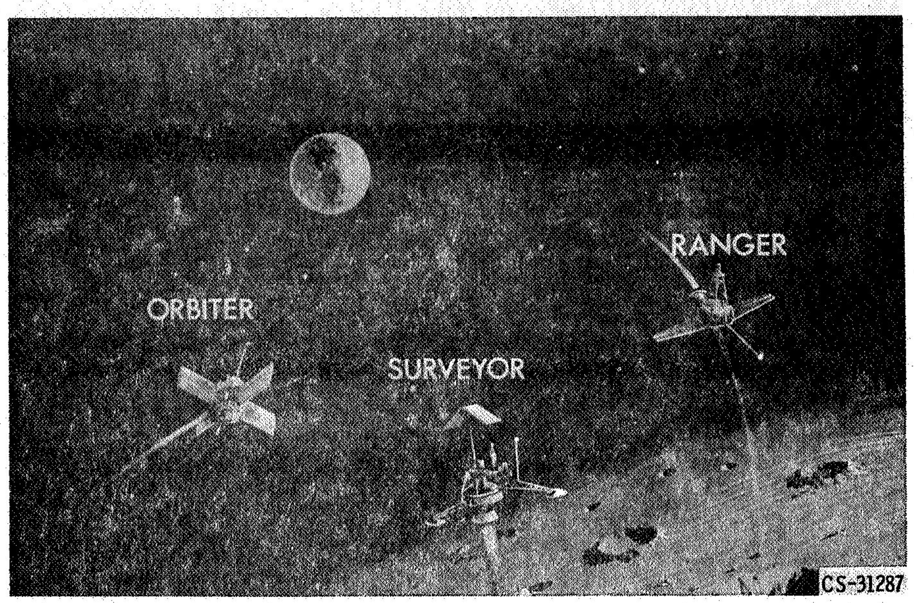

Figure 1. - Unmanned lunar spacecraft, with their robot cameras are preparing the way for manned exploration of the moon.

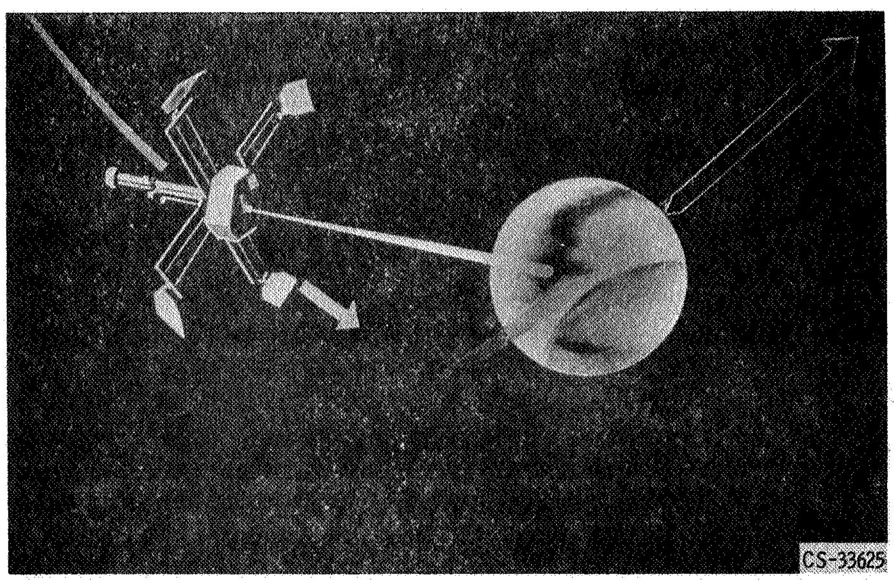

Figure 2. - The Mariner IV probe to Mars traveled through space for eight months to spend 12 hours near the red planets making observations.

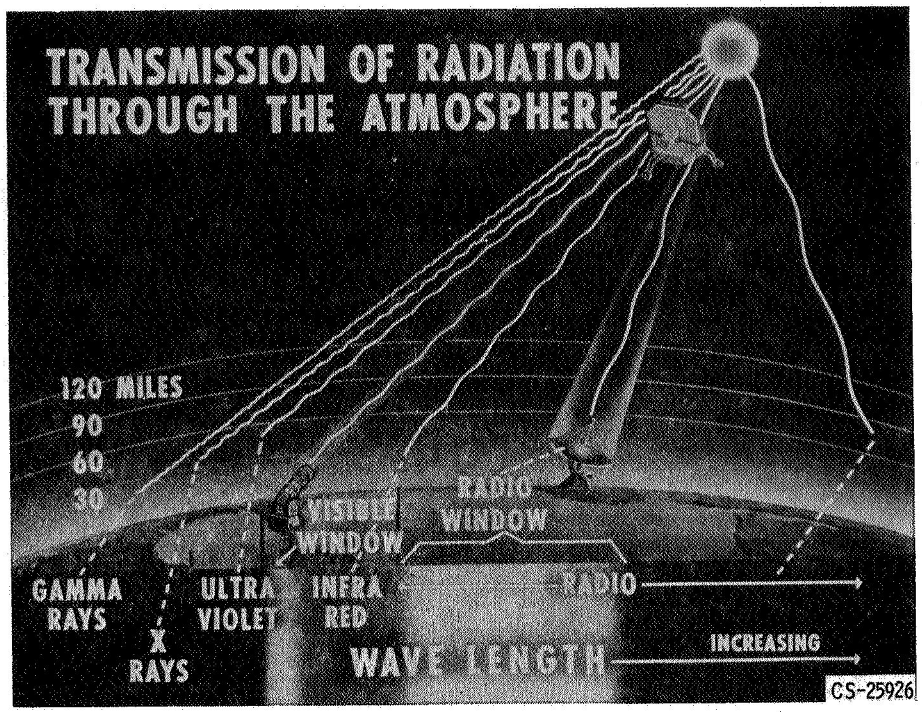

Figure 3. - Our view of the universe is restricted due to the opaque atmosphere surrounding the earth.

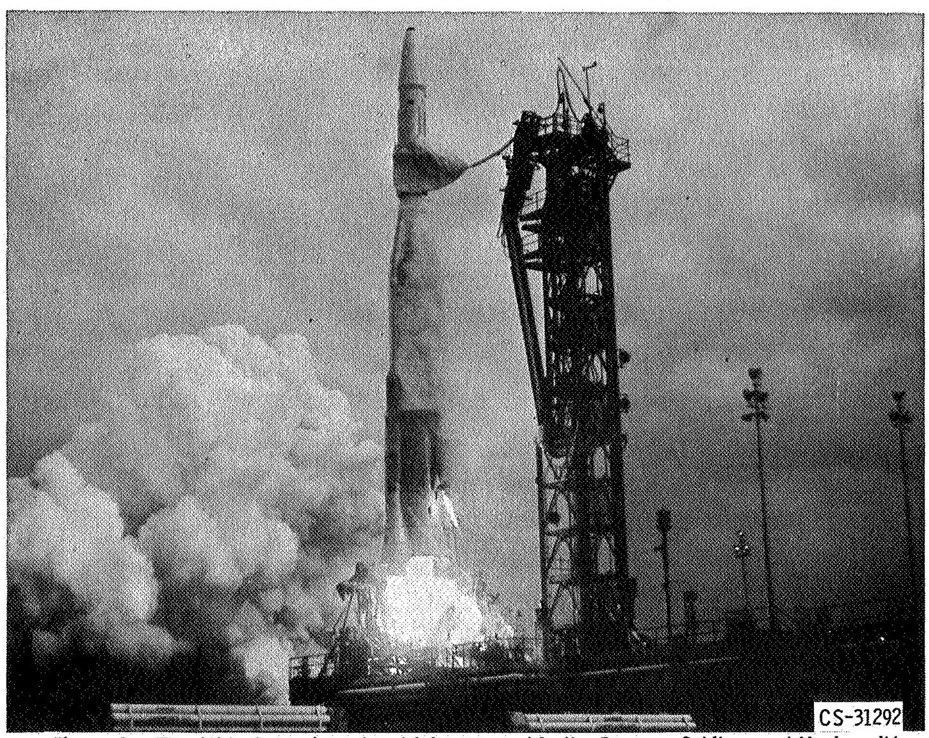

Figure 4. - The Atlas-Agena launch vehicle was used in the Ranger, Orbiter, and Mariner IV launches.

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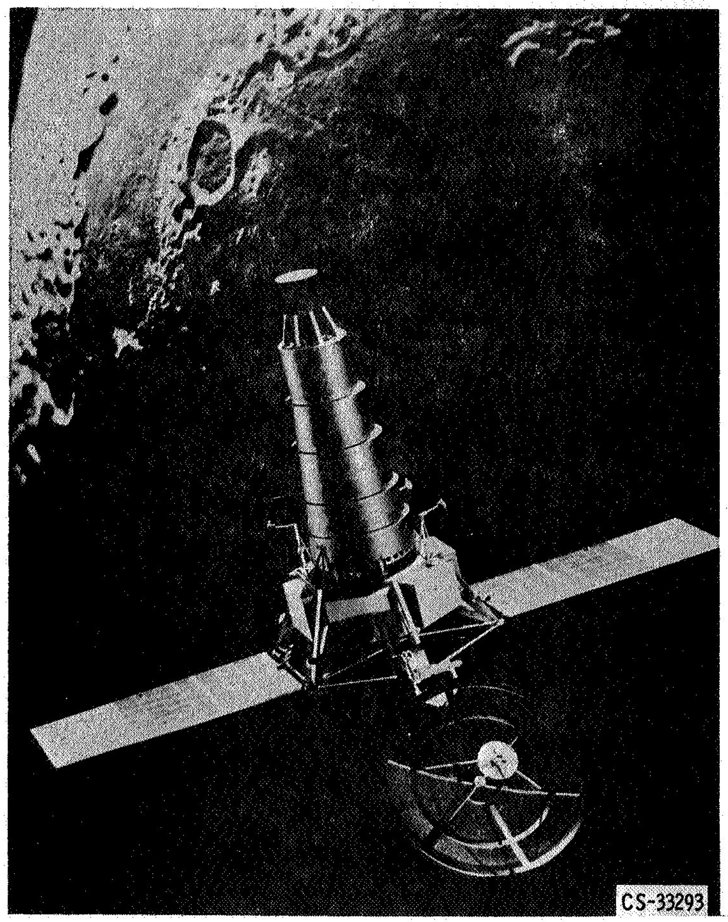

Figure 5. - Rangers VII, VIII, and IX provided the first close-up view of the lunar surface.

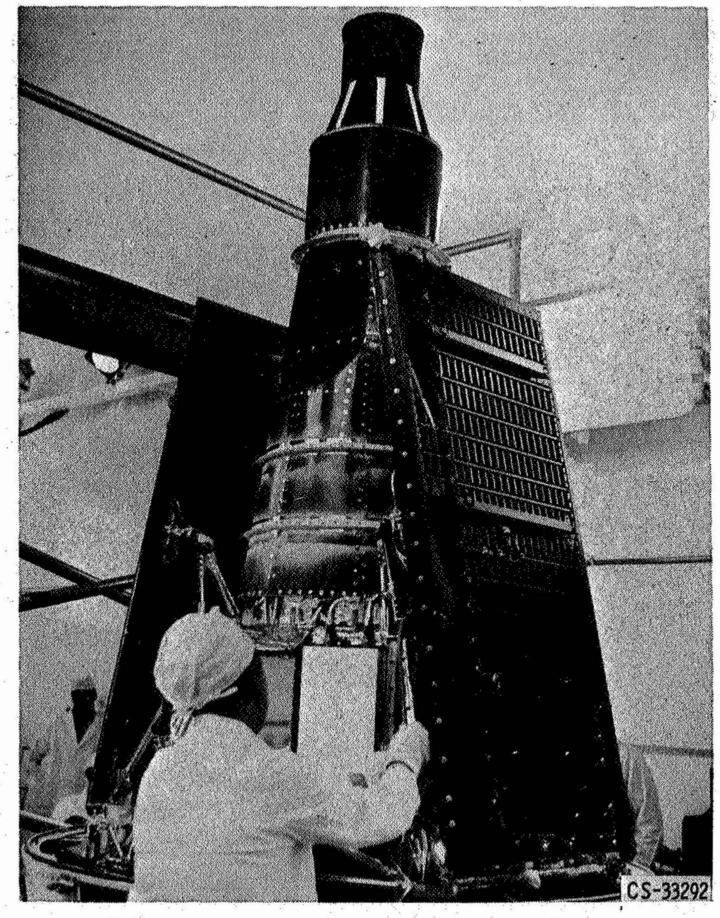

Figure 6. - Ranger is mounted on the Agena in launch configuration.

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TYPICAL RANGER LAUNCH TO MOON

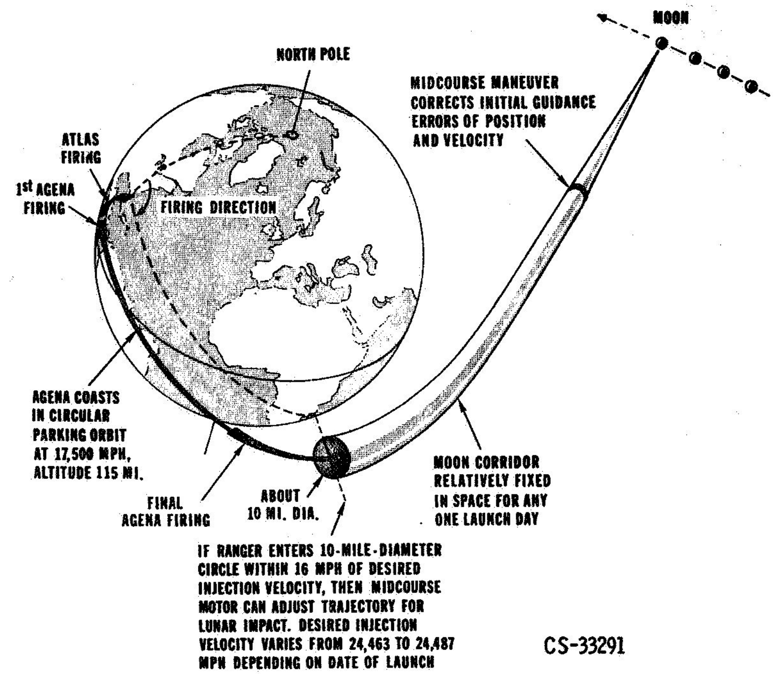

Figure 7.

TRAJECTORY LIMITATIONS ON RANGER PHOTOGRAPHIC MISSIONS

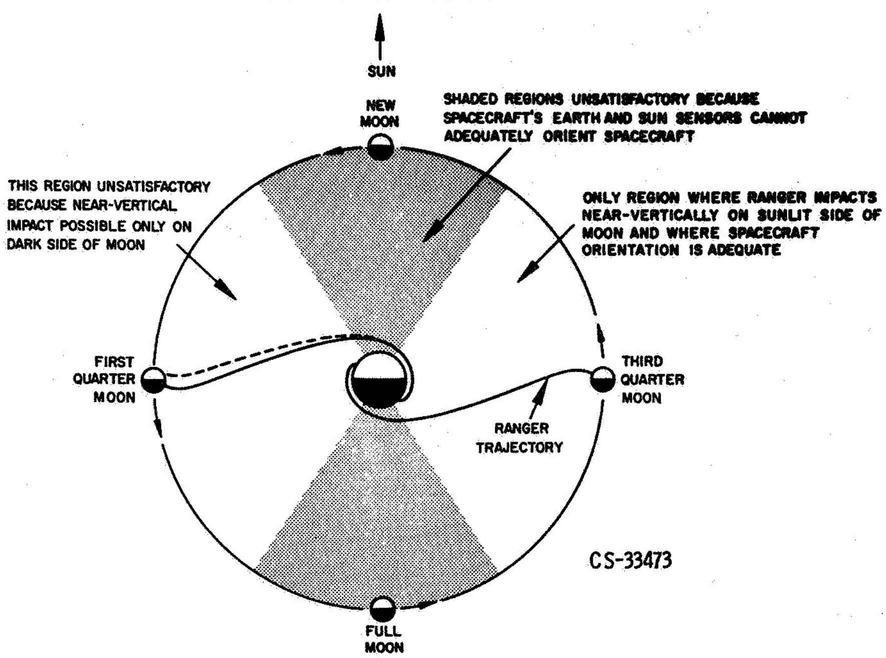

Figure 8.

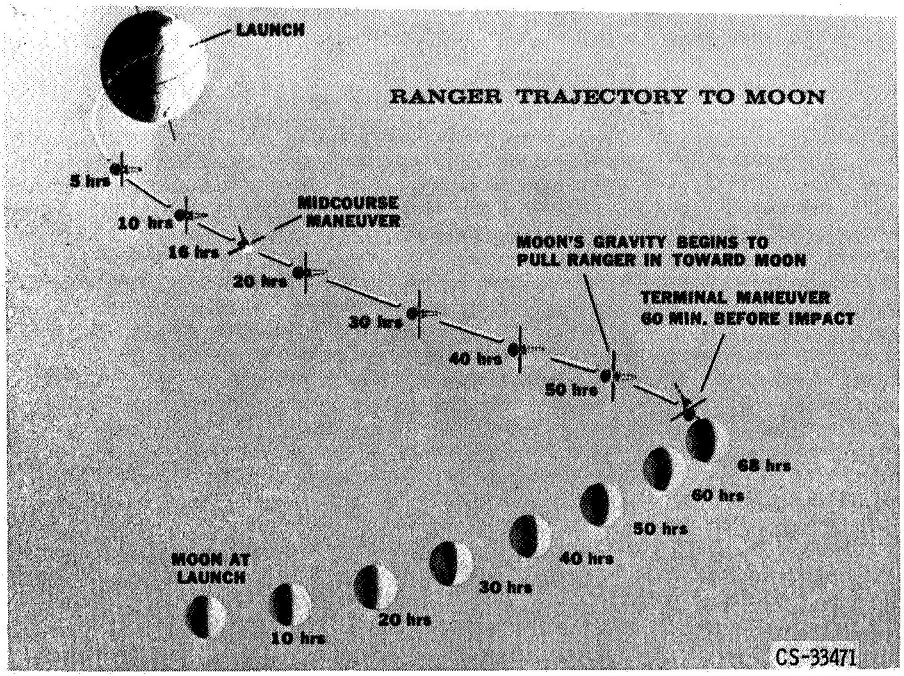

Figure 9.

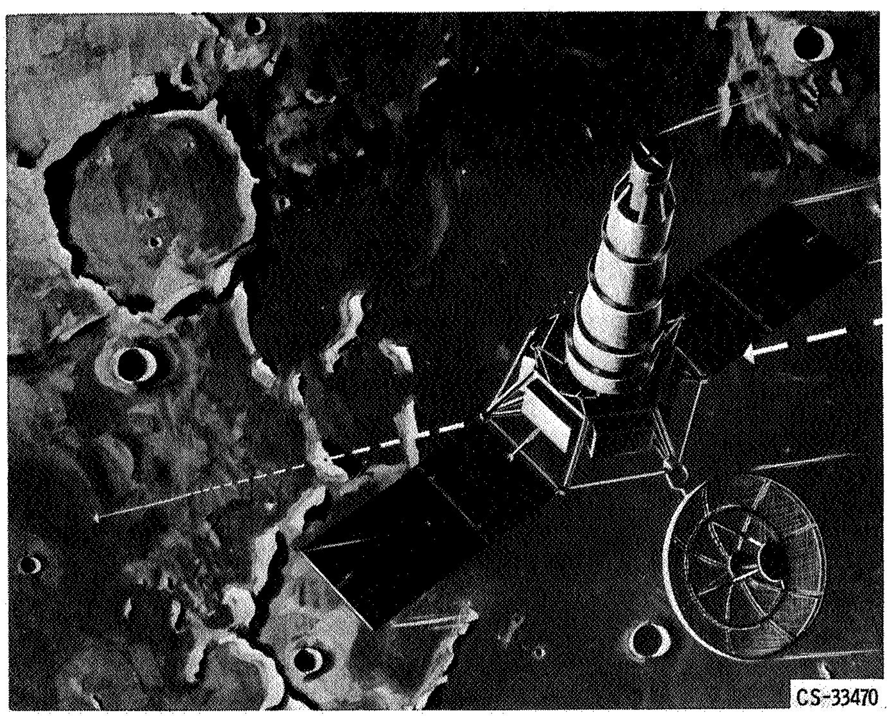

Figure 10. - The terminal maneuver of the Ranger points the cameras along the flight vector.

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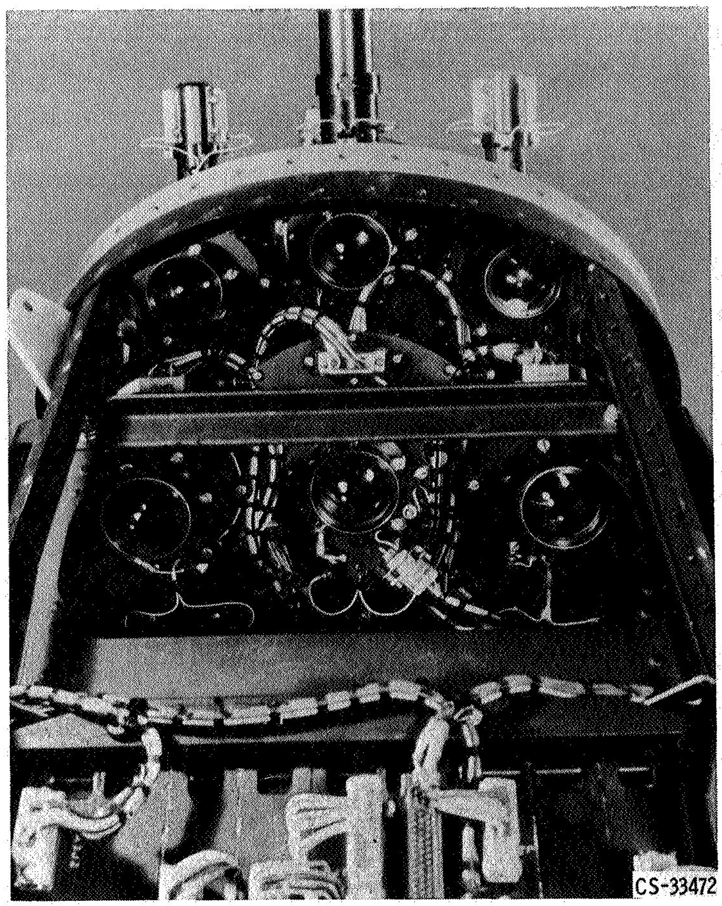

Figure 11. - The Ranger camera system provided over 4000 quality photographs on each of the Ranger missions.

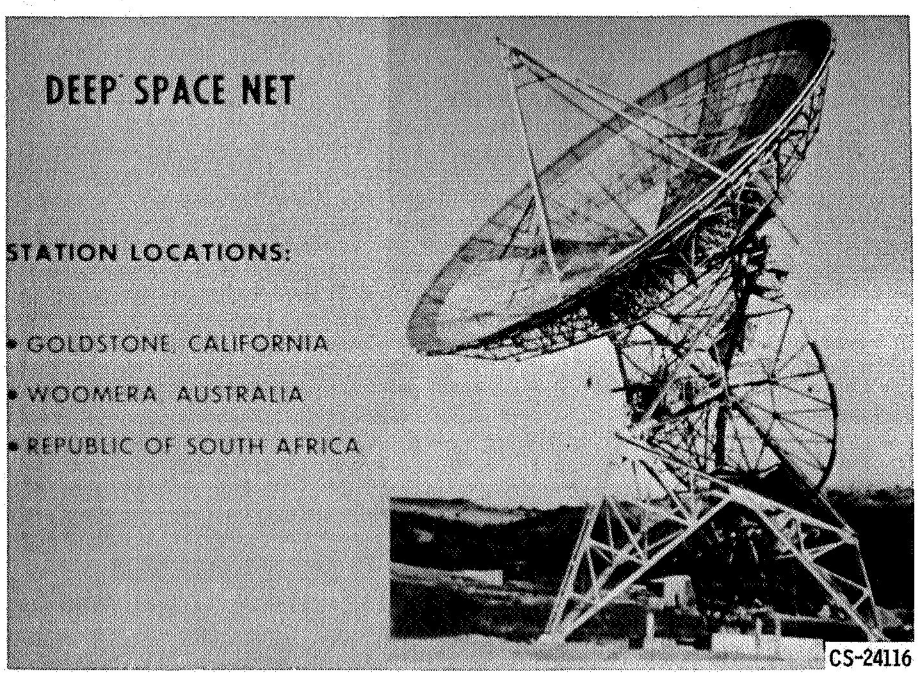

Figure 12. - Antennas such as this 80 foot parabolic dish provide the communications link with the probes to the Moon and Mars.

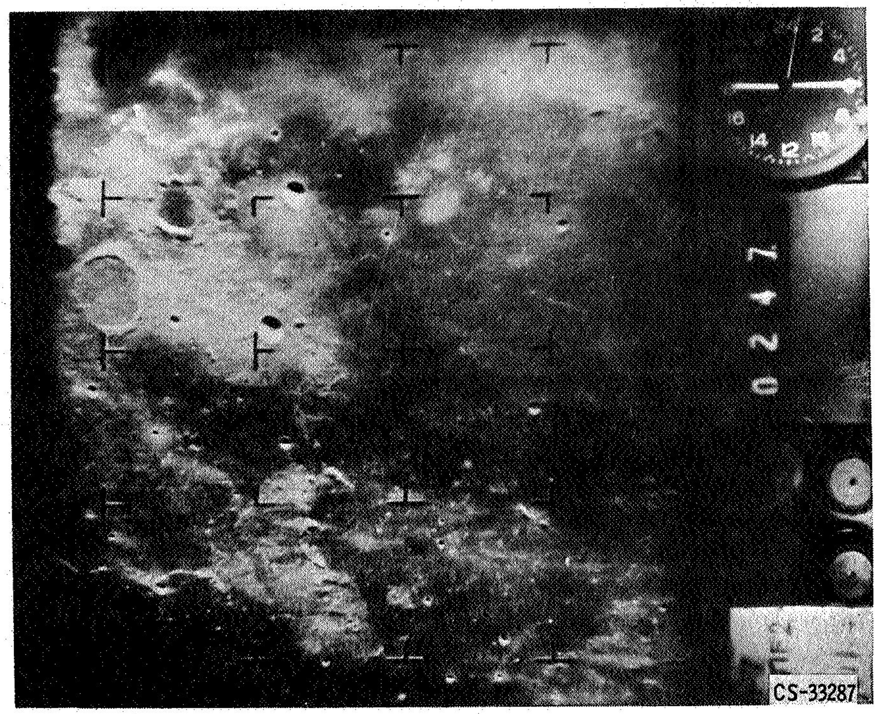

Figure 13. - This Ranger VII Moonscape includes data to identify the frame number, time, camera and mission.

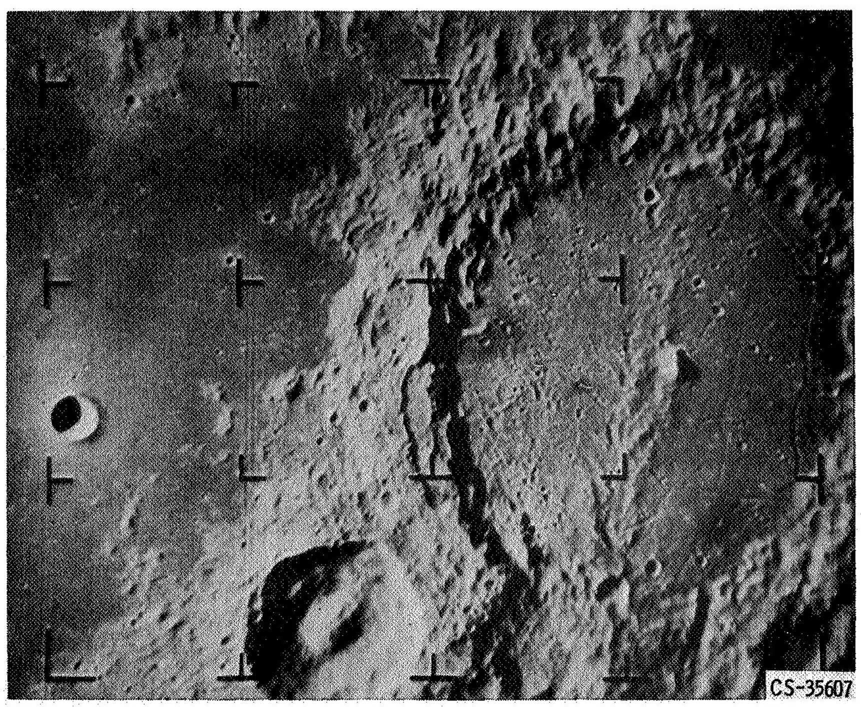

Figure 14. - This Ranger IX photo from 58 miles above the Moon shows the craters Alphonsus (right) and Alpatrogius (bottom) and the adjacent mare.

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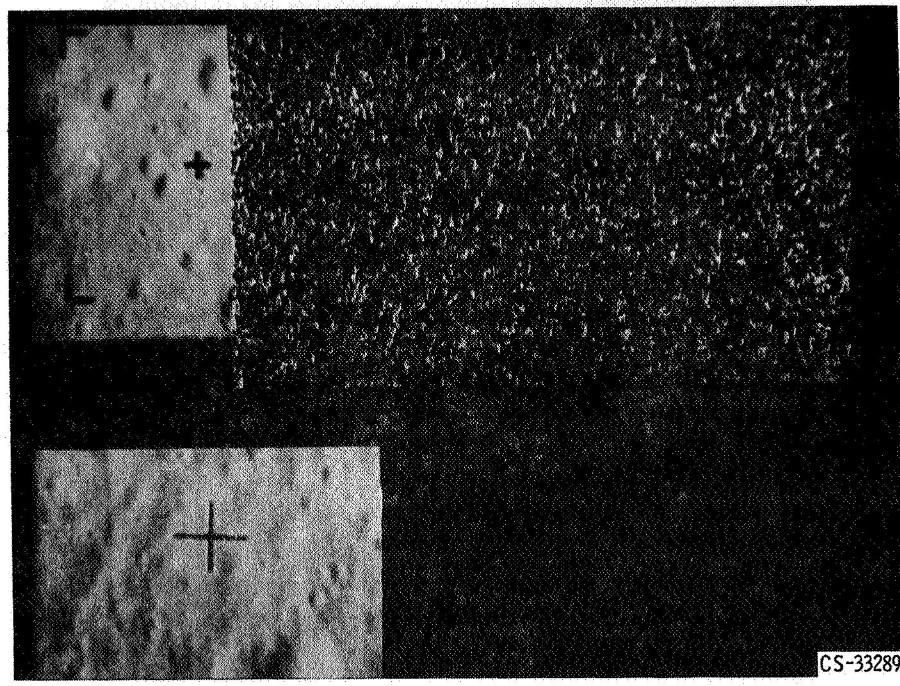

Figure 15. - The final transmission from Ranger VII shows a complete P-1 photo from 3000 feet and a partial P-3 photo from 1000 feet. Receiver noise replaces the final third of the P-3 photo at time of impact.

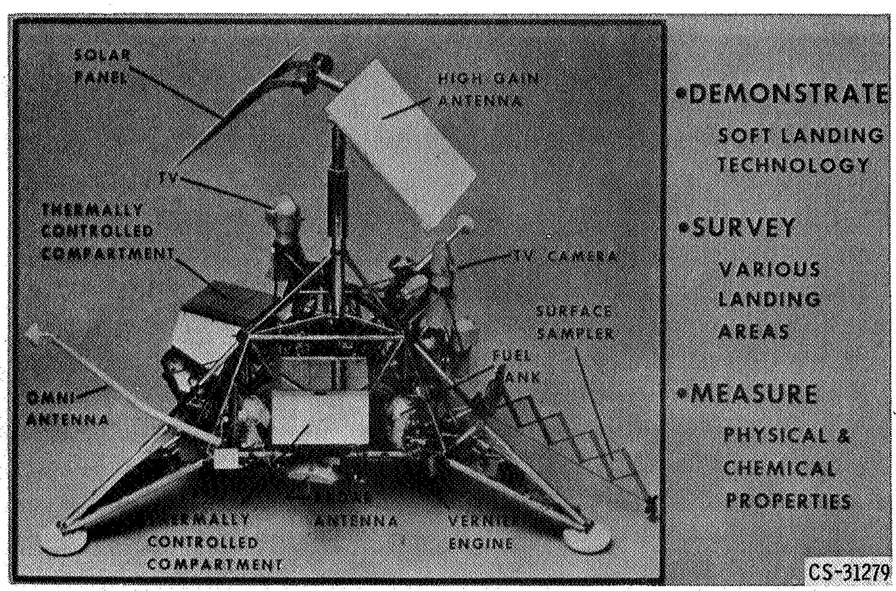

Figure 16. - The 2150 pound Surveyor is designed to soft land its instrument package on the Moon.

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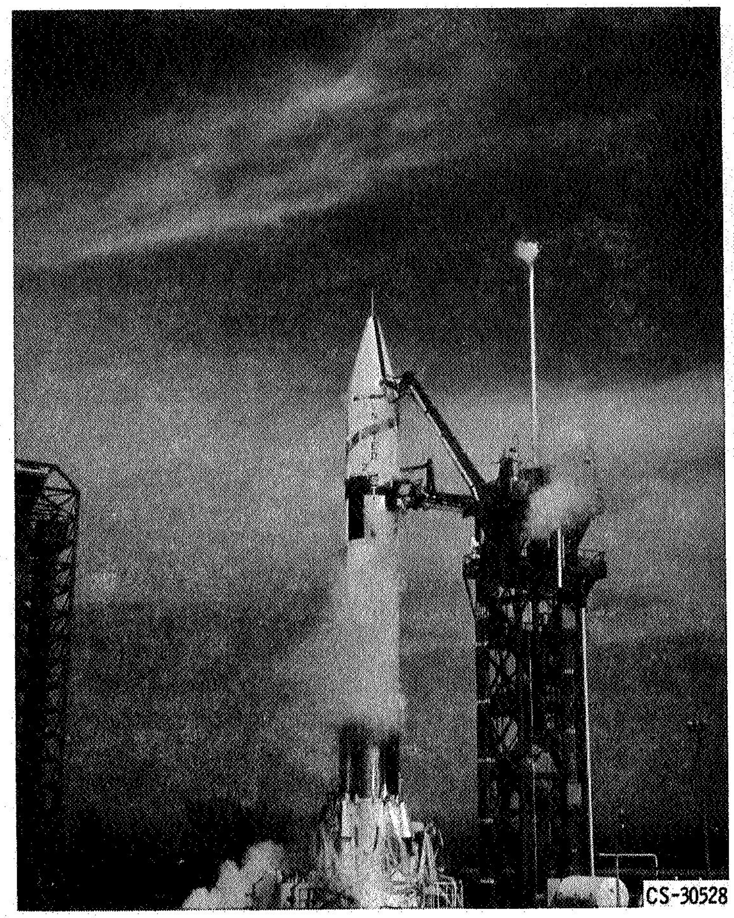

Figure 17. - The Atlas-Centaur launch vehicle used in the Surveyor launches.

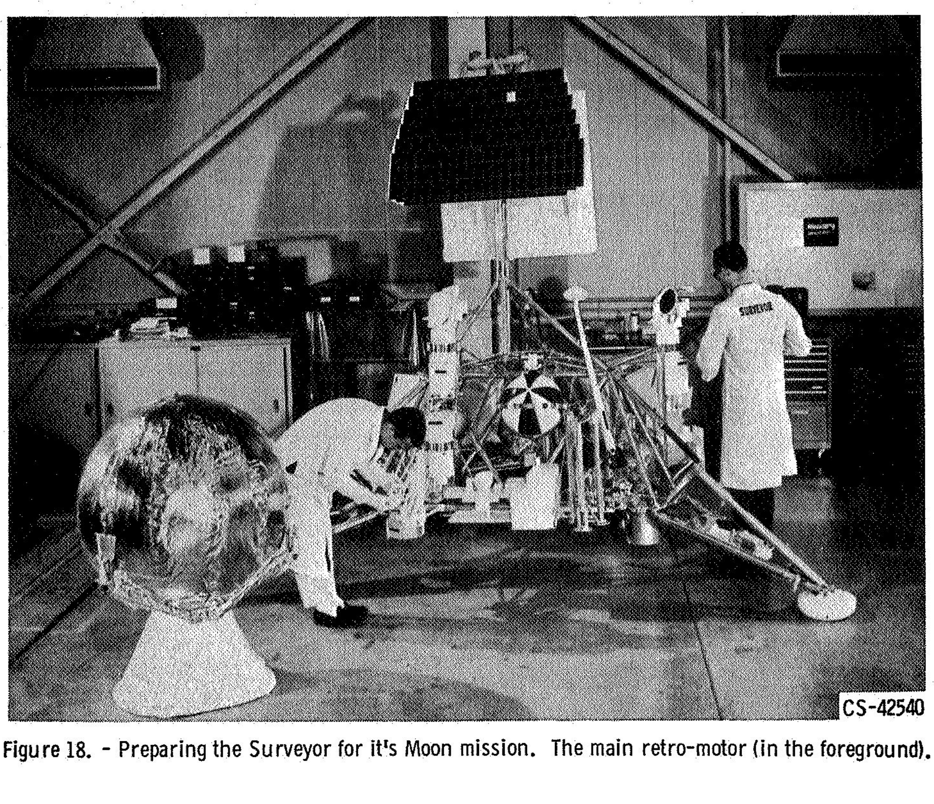

Figure 18. - Preparing the Surveyor for it's Moon mission. The main retro-motor (in the foreground).

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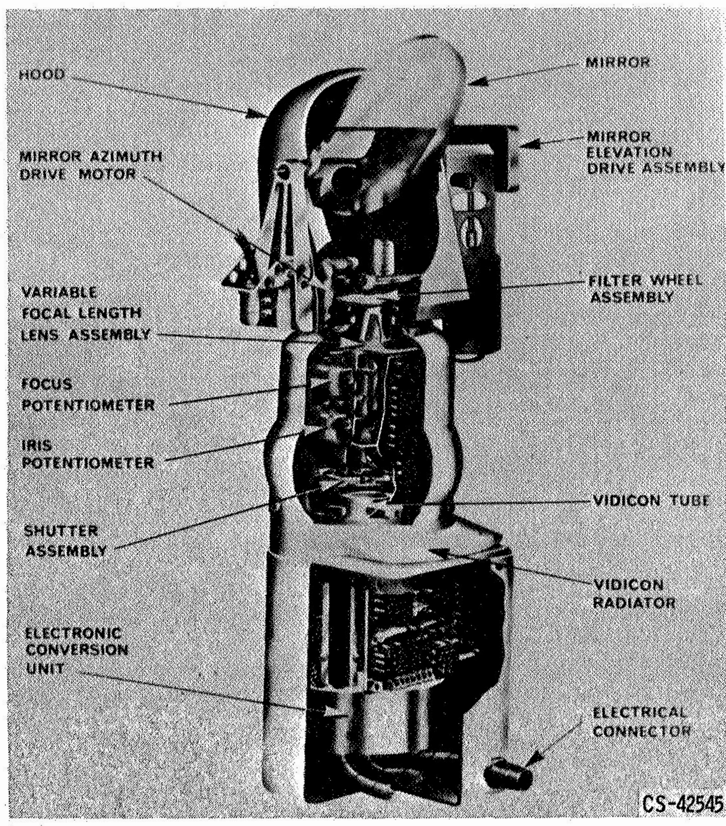


Figure 19.

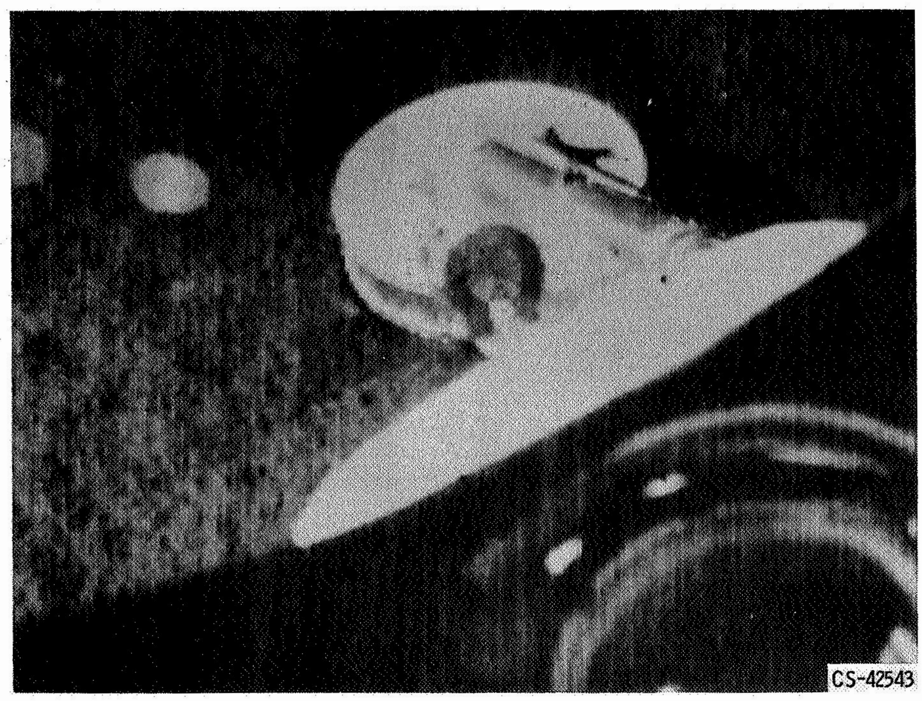


Figure 20. - Surveyor I photograph of it's landing pad, 200 line scan mode. Image at the bottom is a reflection of the camera lens.

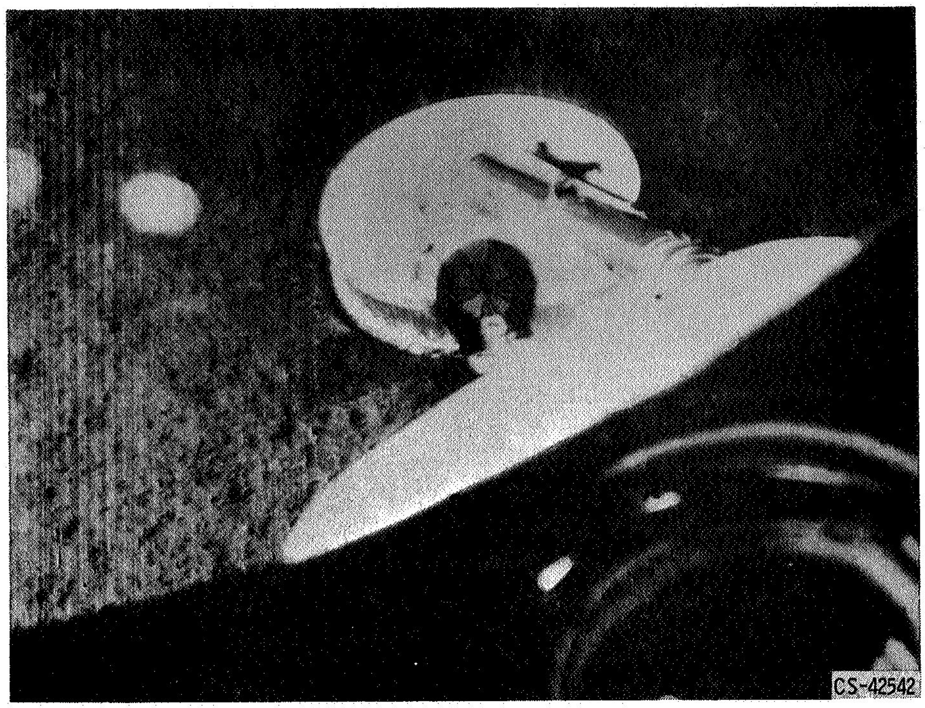
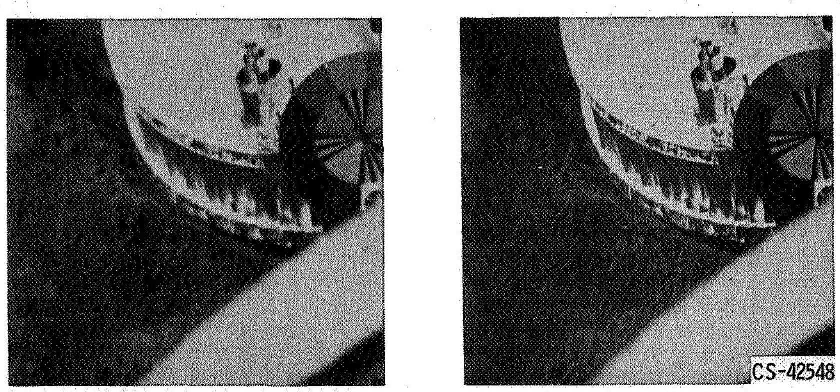


Figure 21. - Surveyor I photo in 600 line scan mode. Note the improvement over figure 20. Bright spots to the left are sun reflections in the camera.



Before enhancement After enchancement

Figure 22. - Computer processing of the Surveyor photos gave additional detail to the photos. The frame on the right has a resolution of about 0.02 inches.

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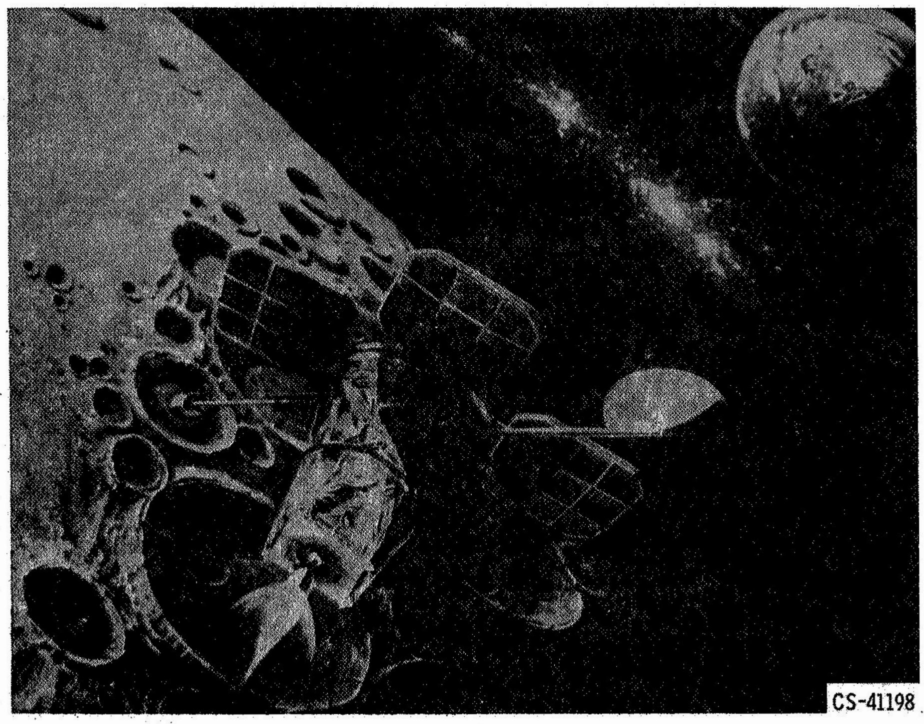
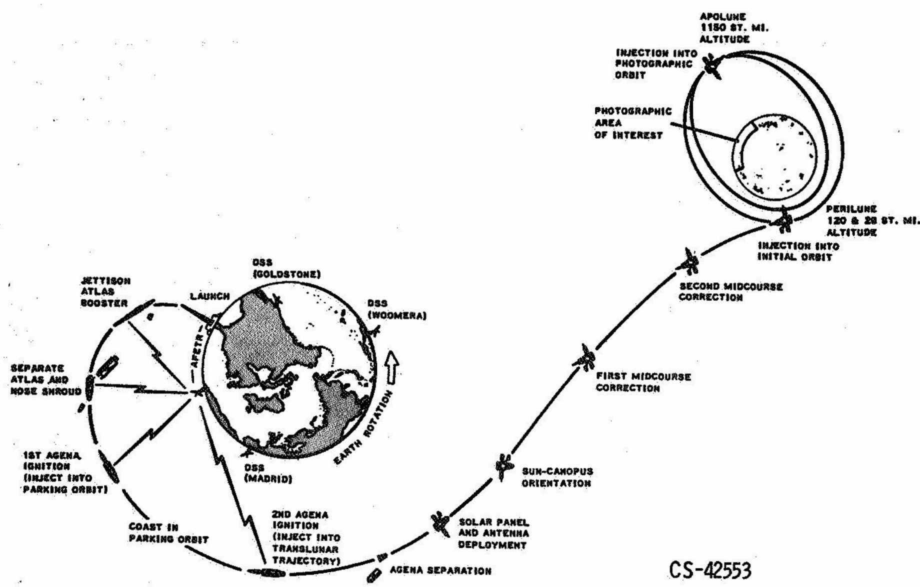
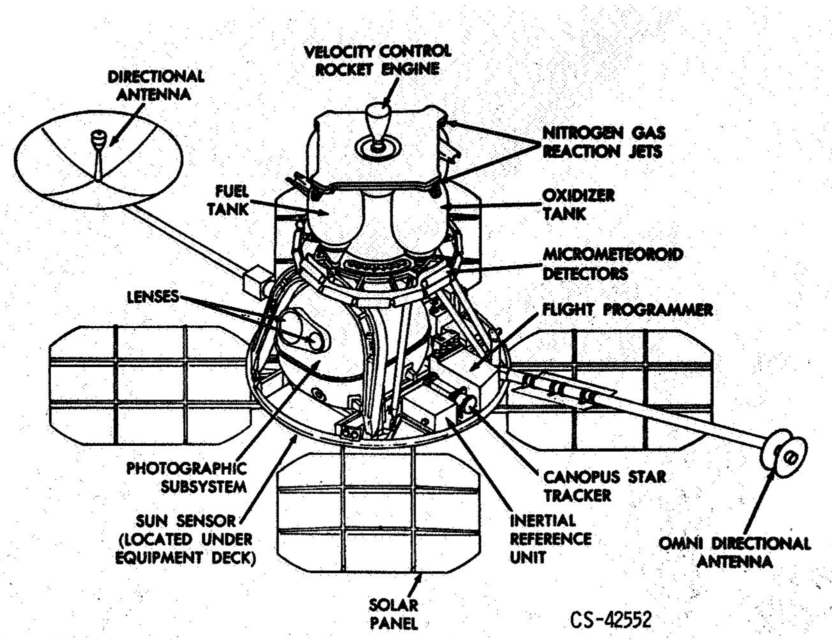


Figure 23. - The Lunar oribiter spacecraft.



TYPICAL ORBITER FLIGHT PROFILE

Figure 24.



LUNAR ORBITER SPACECRAFT

Figure 25.

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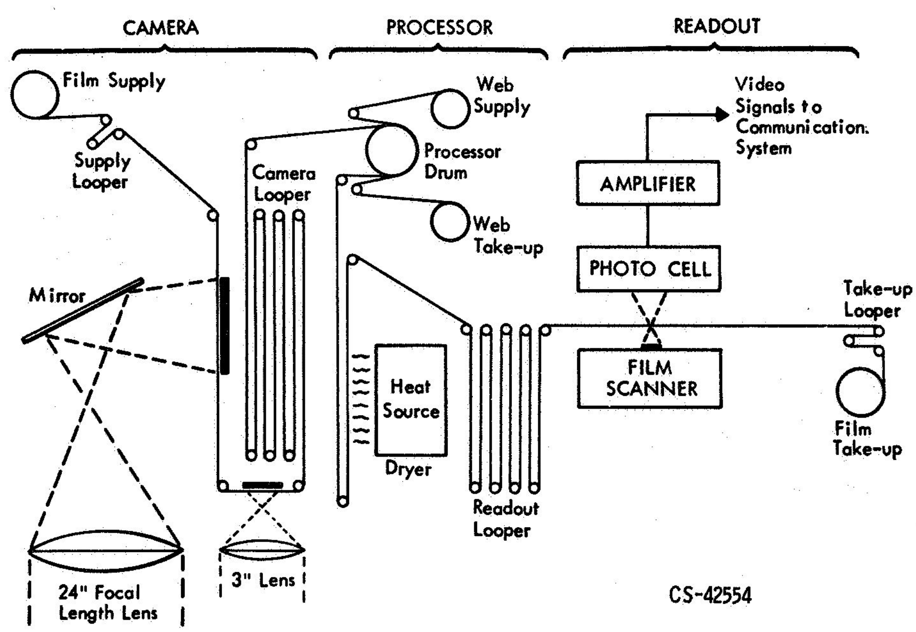

Figure 26. - Orbiter photographic subsystem.

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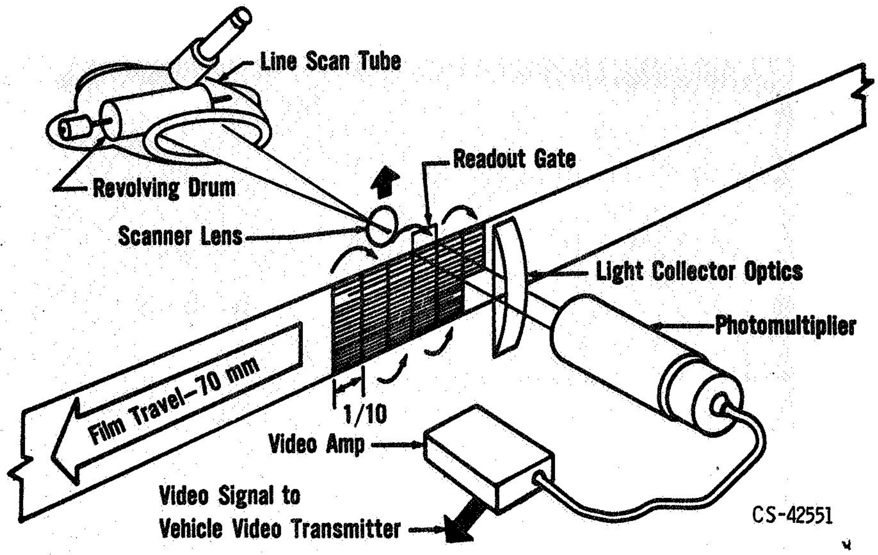

Figure 27. - Orbiter photograph readout system.

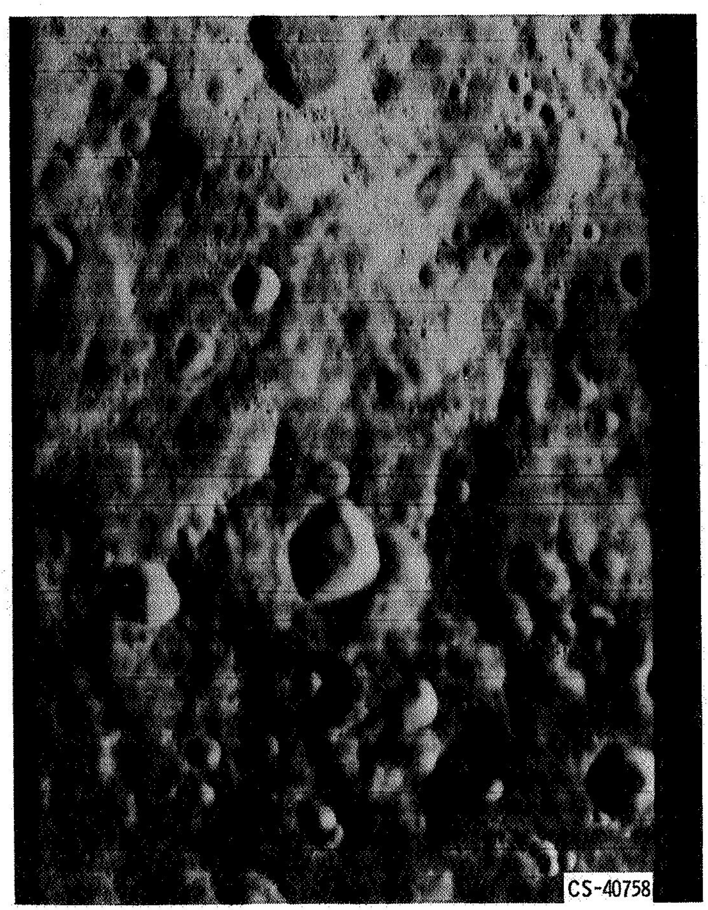

Figure 28. - Reassembled orbiter photograph. (Note pre-exposed edge data).

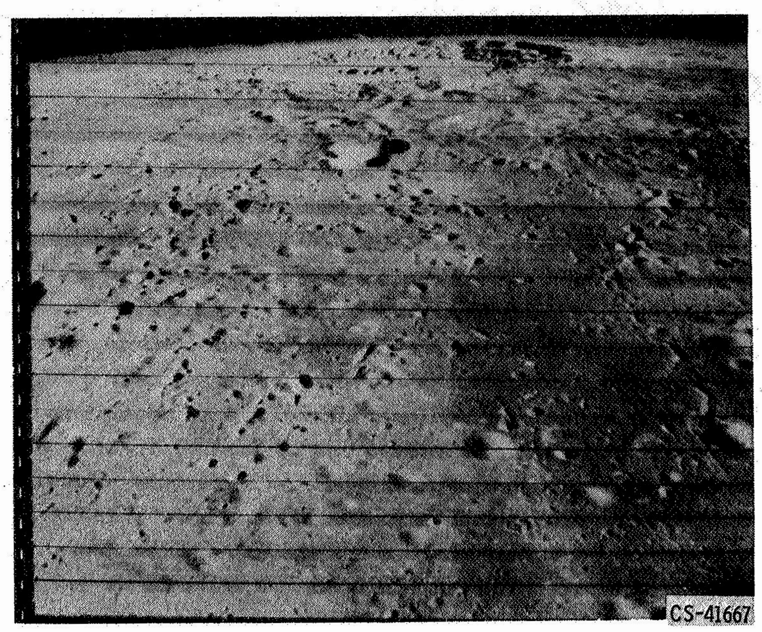

Figure 29.

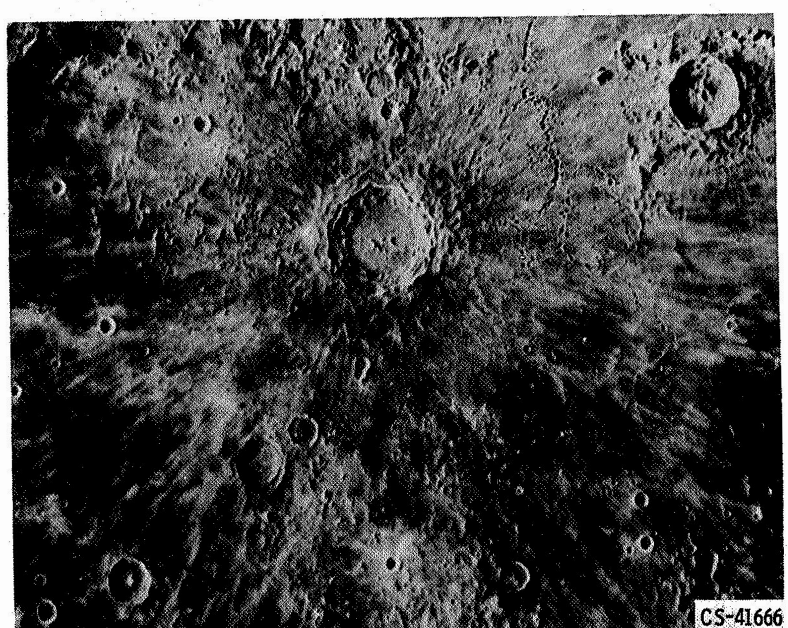

Figure 30.

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Figure 31.

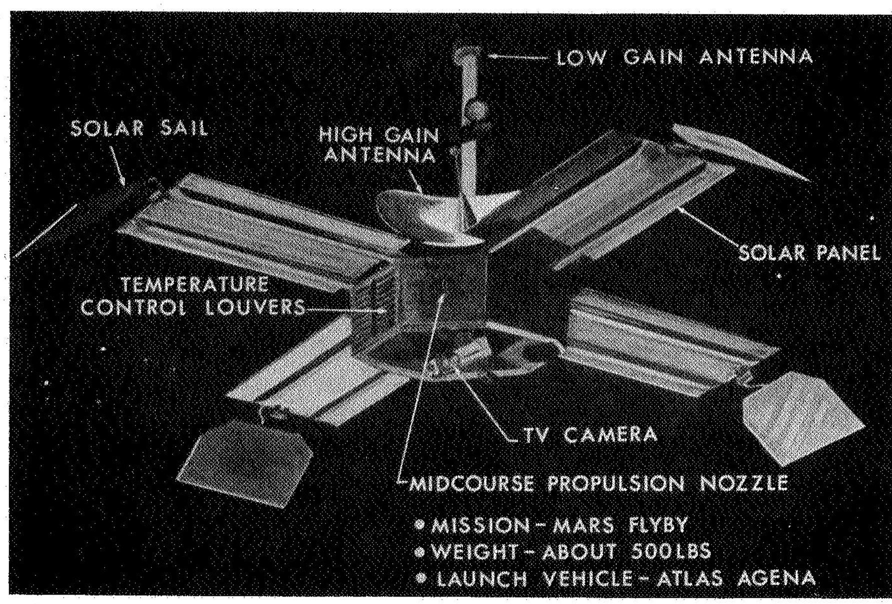


Figure 32. - Mariner IV spacecraft.

CS-31281

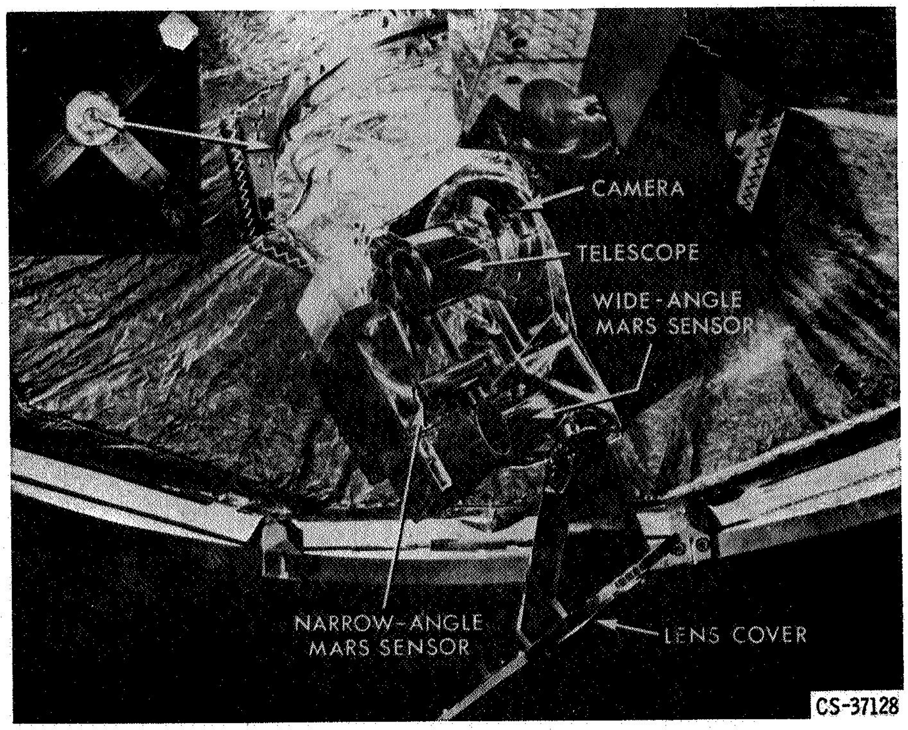
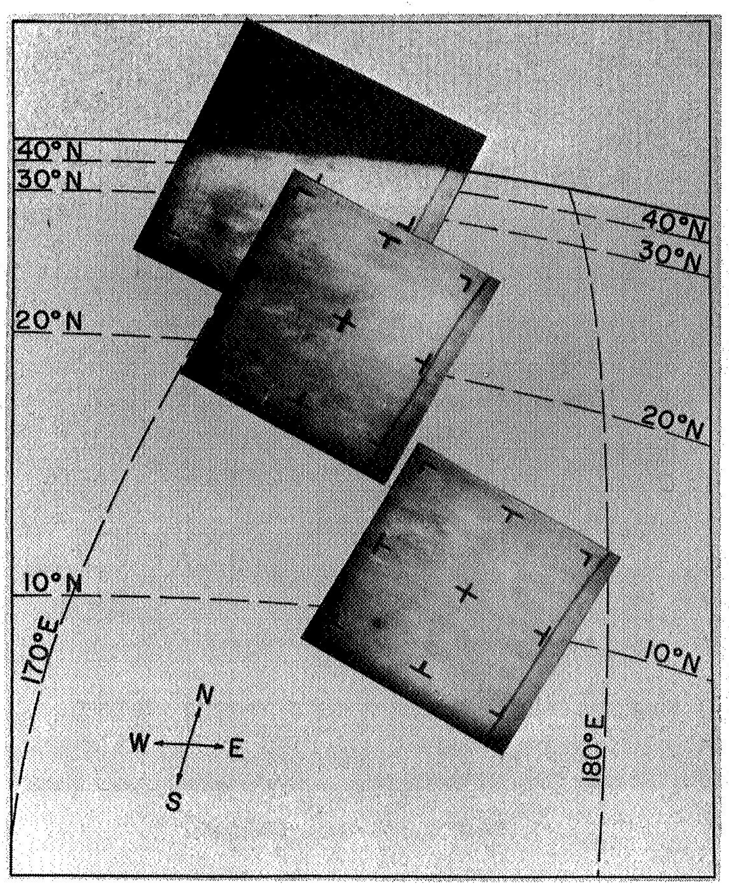


Figure 33. - The Mariner IV camera system.



CS-36834

Figure 34. - First three photographs from the Mariner IV mission.

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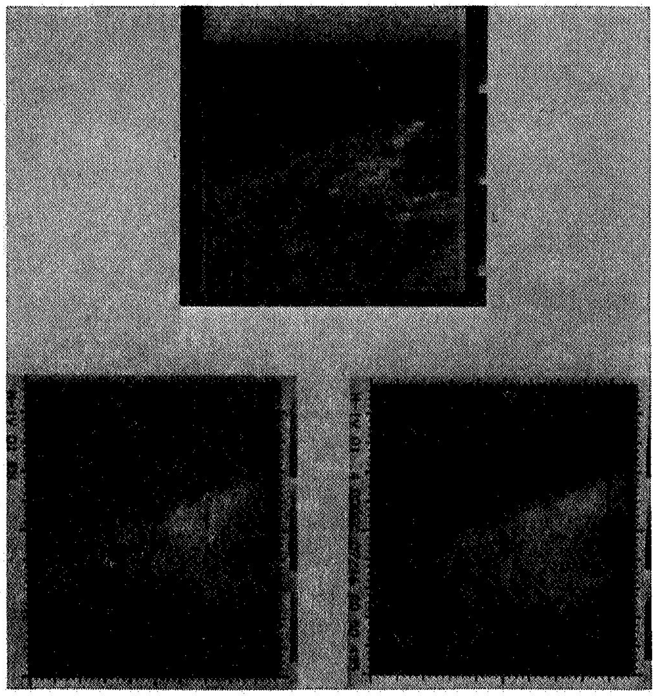

CS-42546

Figure 35. - First frame of the Mariner IV mission. Bottom left: frame as initially received. Bottom right: missing data is replaced on second transmission. Top: computer enhancement, the finished photograph.

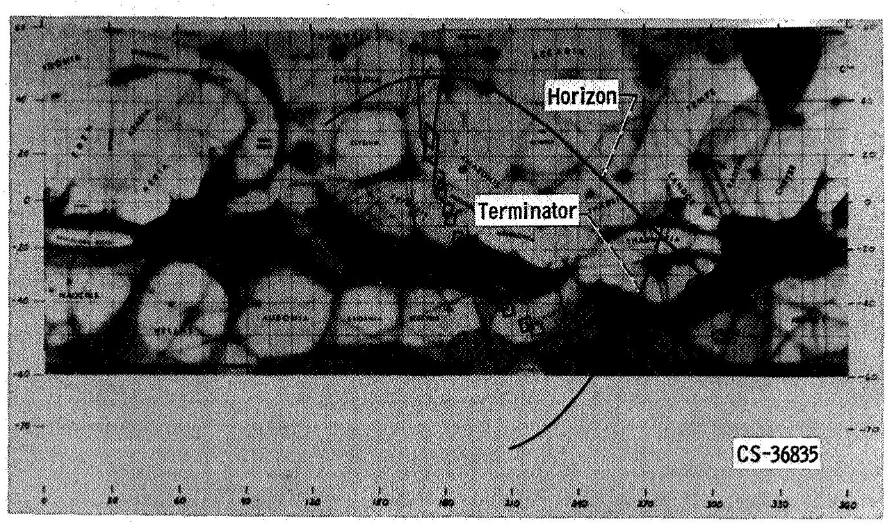

Figure 36. - Map of Mars showing the location of the individual Mariner IV photographs.

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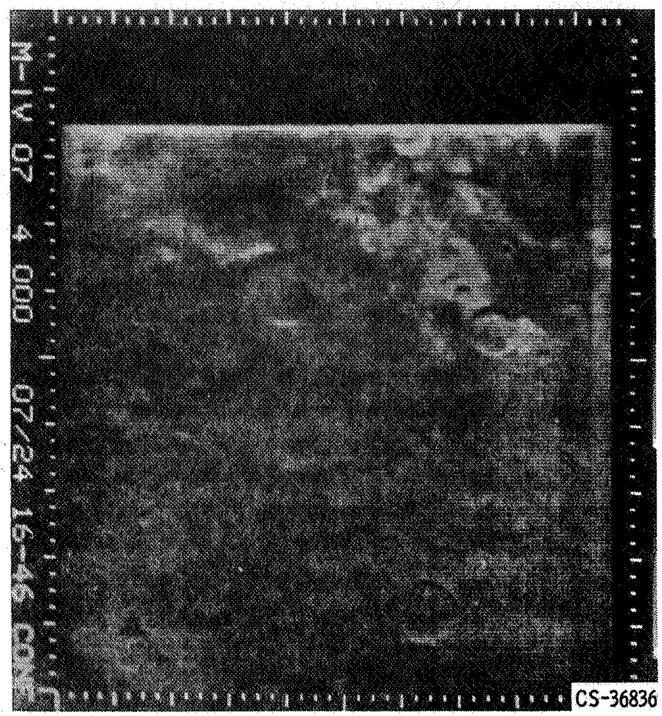

Figure 37. - Frame No. 7 from the Mariner IV probe.

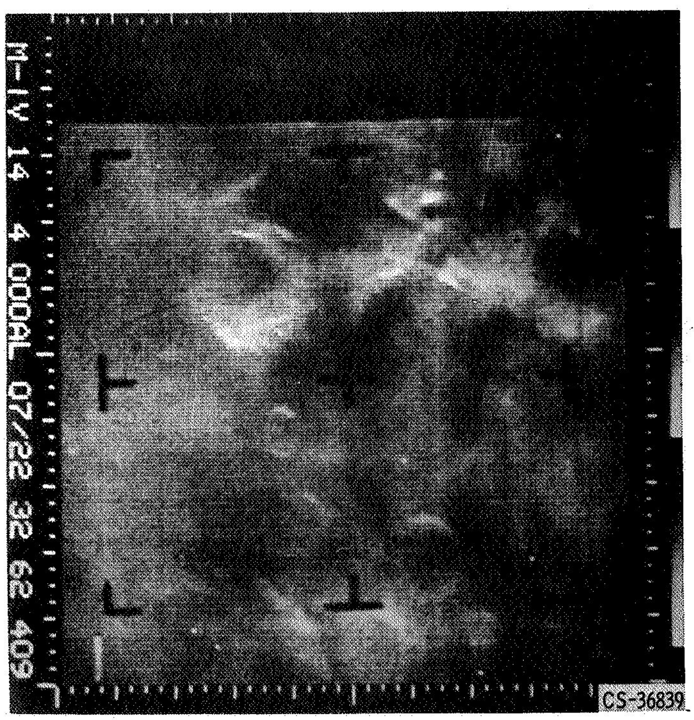

Figure 38. - Frame No. 14 from the Mariner IV probe.

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